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Speed Calculations and the Expert Witness

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SPEED CALCULATIONS AND THE EXPERT WITNESS

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There has been a recent increase in the use of expert witness testimony relating to speeds of vehicles involved in collisions. This has resulted in a need for jurists and lawyers to become increasingly informed of the fundamental physical laws which form the basis of this testimony. The purpose in writing this paper is to discuss in a legal context the most commonly used physical laws in order to clarify an area which has become clouded by the use of incomplete data and erroneous hypotheses.

After a consideration of the Nebraska position, the physical laws used in establishing speed on the basis of skid marks will be discussed with special emphasis on their application and limitations.[1] The use of experiments by the expert witness, related physical laws, and a consideration of methods used by expert witnesses in Nebraska will follow in that order.[2]

I. GENERALLY

Two elements are required to justify the use of expert testimony. These elements are: first, a subject matter outside the knowledge of the average layman; and, second, such skill, knowledge, or experience on the part of the witness which will aid the trier in the search for truth.[3] The latter element, the qualification of the witness, causes little concern. The general rule is that an expert witness' qualifications is a matter for the trial judge's discretion,

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1 For a review of the method used by the New York City Police Department see Lucius v. Herman, 174 Misc. 235, 20 N.Y.S.2d 149 (New York City, Munic. Ct. 1940).

2 This article is limited to establishing speed of automobiles involved in accidents. The wider field of accident reconstruction has been properly deferred to a later time for a more intensive and extensive consideration. Those interested in the entire area of accident reconstruction are referred to: Baker, *Limitations on Accident Reconstruction,* 8 DEFENSE L.J. 3 (1960).

3 McCORMICK, EVIDENCE § 13 (1954). Professor Wigmore maintains that the only true criterion is: "On *this subject* can a jury from *this person* receive appreciable help?" 7 WIGMORE, EVIDENCE § 1923 at 21 (3d ed. 1940).

reviewable only for abuse.[4] However, whether the subject matter is within the knowledge of the average layman becomes a real issue in automobile accident cases. The average layman has a general knowledge of the operation of motor vehicles. From actual experience, he knows how automobiles behave under various conditions. The argument is made that the expert testimony invades the province of the jury.[5] Professor Wigmore takes strong exception to this rule, urging its entire repudiation.[6] However, the general rule is that expert opinion is admissible where the subject matter is such that a jury cannot be expected to draw correct inferences from the facts.[7]

In an automobile accident case the mere existence of skid marks is not evidence of negligence, "The skidding of an automobile may be made the basis of a finding of negligence only if it was due to some negligent conduct on the part of the motorist."[8] The skid marks must first be interpreted by an expert before they have any evidential value. Such interpretation may be used to corroborate, to impeach, or to establish a prima facie case.[9] Before considering

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4 McCORMICK, EVIDENCE § 13 at 29 (1954); see also 2 WIGMORE, EVIDENCE § 561 (3d ed. 1940).

5 In Danner v. Walters, 154 Neb. 506, 48 N.W.2d 635 (1951), testimony of an expert witness as to the point of impact based on skid marks was excluded because such testimony invaded the province of the jury.

6 Professor Wigmore says: "This phrase is made to imply a moral impropriety or a tactical unfairness in the witness' expression of opinion.

"In this aspect the phrase is so misleading, as well as so unsound, that it should be entirely repudiated. It is a mere bit of empty rhetoric. There is no such reason for the rule, because the witness, in expressing his opinion, is not attempting to "usurp" the jury's function nor could he if he desired. He *is not* attempting it, because his error (if it were one) consists merely in offering to the jury a piece of testimony which ought not to go there; and he *could not* usurp it if he would, because the jury may still reject his opinion and accept some other view, and no legal power, not even the judge's order, can compel them to accept the witness' opinion against their own." 7 WIGMORE, EVIDENCE § 1920 at 17-18 (3d ed. 1940); Ladd, *Demonstrative Evidence and Expert Opinion*, WASH. U.L.Q. 1, 4 (1956): "It is the function of the jury to make the decisions upon the ultimate questions of fact raised by the legal issues of the case. The forward looking view of the law of evidence permits the expert to express his opinion upon the same ultimate issues, but the jury is not compelled to accept the expert's view upon the ultimate facts in issue."; *accord*, Grismore v. Consolidated Prods. Co., 232 Iowa 328, 5 N.W.2d 646 (1942).

7 1 BLASHFIELD, AUTOMOBILE LAW AND PRACTICE § 6311 (1948).

8 1 BLASHFIELD, AUTOMOBILE LAW AND PRACTICE § 749 at 680 (1948).

9 Reath, *Scientific Data and Expert Opinion—Its Use In Auto Accident Cases*, 24 INS. COUNSEL J. 99 (1957).

the applicable physical laws, the Nebraska position as to the admissibility of such evidence will be reviewed.

II. THE NEBRASKA POSITION

The Nebraska position originates with *Blado v. Draper*,[10] a 1911 case, involving the collision of a one horse carriage and an automobile. The use of expert testimony was sanctioned when a witness was allowed to testify to the stopping distance of an automobile running at various speeds on Eleventh Street in Lincoln, Nebraska. The court said: "The witness clearly qualified himself as an expert handler, driver and dealer in automobiles, and we are satisfied that the evidence complained of was properly admitted."[11] The testimony given in this case did not refer directly to skid marks. The testimony was to the effect that at X miles per hour the automobile should be stopped in Y number of feet. The modern expert witness testifies that in order to leave Y number of feet of skid marks the automobile would have to be traveling at X miles per hour.

The first case involving skid marks to reach the Nebraska Supreme Court was *McKinney v. Wintersteen*,[12] an automobile-pedestrian accident. Here, an automobile hit a six year old girl who was crossing a paved public alley in Lincoln, Nebraska. The automobile left twelve feet of skid marks. The expert witness[13] testified that he had made experiments in the alley with a car of similar weight and good brakes. The witness then stated the lengths of skid marks left at various speeds. The court stated:[14]

> The evidence of skid marks on the roadway made by an automobile makes the question of speed and control of said automobile one for the jury, and a qualified expert may give his opinion as to the speed of the automobiles based on the length of the skid marks made by it.

It is necessary to interrupt this chronological consideration of the Nebraska position with regard to skid marks and speed in order to examine the case of *Danner v. Walters*.[15] This case was a suit for damages resulting from a car-truck collision. The testimony

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[10] 89 Neb. 787, 132 N.W. 410 (1911).

[11] *Id.* at 790, 132 N.W. at 412.

[12] 122 Neb. 679, 241 N.W. 112 (1932).

[13] There is no doubt that the witness must be an "expert." In a subsequent case, Piechota v. Rapp, 148 Neb. 442, 27 N.W.2d 682 (1947), the court excluded testimony based on skid marks because the witness giving the testimony, a county sheriff, was not qualified to do so.

[14] McKinney v. Wintersteen, 122 Neb. 679, 681, 241 N.W. 112, 114 (1932). (Citations omitted).

[15] 154 Neb. 506, 48 N.W.2d 635 (1951).

of a highway patrolman as to the point of impact based upon tracks, marks, and other circumstances surrounding the accident, was excluded. The court stated:[16]

> A witness may describe the marks that he has observed near the place of an accident. The inference to be drawn from the testimony regarding such tire marks, skid marks, or scratches is solely the province of the jury.
>
> The physical facts from which this question was to be answered were all presented to the jury. The issue did not call for the opinion of an expert. The jury was as competent to decide from the facts the point at which the impact took place as was the officer.

The first quoted paragraph has confused some commentators, who have interpreted this to mean that no testimony whatsoever with regard to skid marks will be allowed.[17] However, this first paragraph is limited by the second paragraph to testimony as to the point of impact. This limitation was recognized in *Biggs v. Gottsch.*[18] In *Biggs* two expert witnesses testified, interpreting the meaning of skid marks which resulted from a private car-taxicab collision. One expert testified as to speed based upon the skid marks. This testimony was accepted and was not an issue on appeal. The second expert testified as to the point of impact. The court held this to be error but, because it was not prejudicial testimony, the court refused to reverse. The court did state:[19]

> In the case of Danner v. Walters, 154 Neb. 506, 48 N.W. 635, this court held that an expert cannot give his opinion as to the point of impact because it would be his opinion upon the precise or ultimate issue before the jury, which must be determined by it.

Danner v. Walters, therefore, has no relation to the issue of estimating speed based upon skid marks.[20]

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[16] *Id.* at 516-17, 48 N.W.2d at 641-42.

[17] Reath, *supra* note 9, where Nebraska is listed as a jurisdiction denying admissibility of expert testimony in automobile accidents because such testimony would invade the province of the jury; Parker, *Automobile Accident Analysis By Expert Witnesses,* 44 VA. L. REV. 789 (1958) where *Danner v. Walter* is cited as standing for the proposition that estimates as to speed based on skid marks are inadmissible.

[18] 173 Neb. 15, 112 N.W.2d 396 (1961).

[19] *Id.* at 28, 112 N.W.2d at 404-05.

[20] A recent decision in the United States Court of Appeals, Lofton v. Agee, 303 F.2d 287 (8th Cir. 1962), reached the opposite conclusion of *Danner v. Walters.* In this case an expert witness testified to the point of impact, angle of impact, and the position of the two vehicles with respect to the center of the roadway at the time of the collision. This evidence was based on the final positions of the vehicles and the skid marks. The court held that the admission of such testimony was neither erroneous nor prejudicial.

Perhaps the leading case on the use of expert testimony to establish speed is *Tate v. Borgman*.[21] This action arose from an intersection accident involving a taxicab and a passenger car. There were sixty one feet of skid marks before the impact, the cab was shoved an additional ten feet, and both cars were extensively damaged. The expert testified to how many feet of skid marks should be left by a car traveling at various speeds. The court, relying upon *McKinney v. Wintersteen*,[22] held that it was prejudicial error for the lower court to strike this expert testimony.

Tate v. Borgman[23] was cited as controlling in *Nisi v. Checker Cab Co.*,[24] an auto-pedestrian accident. In this case a taxicab on a clear dry night laid down sixty-nine feet of skid marks after hitting a pedestrian and threw the pedestrian an additional twenty-one to twenty-three feet. The expert witness testified that he would estimate the speed of the taxicab to have been thirty-four or thirty-five miles per hour, and that this was a minimum speed. Such speed was over the maximum speed limit for the area. The court sustained the admission of this expert testimony.

In *Solomon Dehydrating Co. v. Guyton*,[25] involving an intersection collision between a Greyhound Bus and a two-ton truck, the United States Court of Appeals for the Eighth Circuit excluded expert testimony as to the speed of the bus because of insufficient foundation. The witness was a consulting engineer and professor of mechanical engineering at the University of Nebraska. This expert attempted to calculate the speed of the vehicles just prior to the accident on the basis of the type of road surface, the length of the skid marks, the distance the vehicles traveled after the collision, the weights of the vehicles and the relative amount of damage. The expert witness would have testified that the bus must have been traveling at least sixty-five miles per hour. The court said such testimony was properly excluded because there was no evidence supporting a conclusion that the truck was pushed sidewise. The court, however, did say that under Nebraska law the admission of expert testimony as to the speed of an automobile based on the length of skid marks was proper.

The Nebraska position as to the admission of expert testimony to determine speed based upon skid marks is that a qualified

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[21] 167 Neb. 299, 92 N.W.2d 697 (1958).

[22] 122 Neb. 679, 241 N.W. 112 (1932).

[23] 167 Neb. 299, 92 N.W.2d 697 (1958).

[24] 171 Neb. 49, 105 N.W.2d 523 (1960).

[25] 294 F.2d 439 (8th Cir. 1961).

expert may, upon consideration of all necessary factors, estimate the speed at which a vehicle would have had to be traveling to lay down the skid marks which occurred in the accident.

III. EXTENT OF TESTIMONY

Just what can the expert witness prove once he is permitted to testify? The expert witness, on the basis of skid marks, can give the minimum speed that the vehicle in question could have been traveling. The primary reason that the exact speed cannot be given is simply because it cannot be determined. The minimum speed is based upon measurements and physical laws which have few if any variable factors. A calculation of exact speed requires information which is unobtainable, such as the exact brake pressure, the exact period during which the brakes were applied but did not skid, the effect of gear drag when the accelerator is released, the exact area of tire contact with the surface, the change in weight distribution, etc. Besides certainty, the minimum speed gives the driver the benefit of the doubt as to excessive speed.

Since the testimony only gives the minimum speed, what is its value? The value lies in the fact that this is a bare minimum from which the jury may add other considerations to arrive at a verdict. One must then consider the effect on a negligence case when the expert testifies to a minimum speed which is above the posted speed limit or the reasonable speed for the conditions involved. The expert testimony in both *McKinney v. Wintersteen*[26] and *Nisi v. Checker Cab Co.*[27] established that the defendants' cars were exceeding the maximum speed limit.

An estimate of speed based on skid marks is very conservative, because such marks do not show all the evidence of speed. Speed is lost in several ways other than through skidding. First, the vehicle may be slowed down by moderate braking before the wheels begin to slide. Second, there is a reduction in speed while the wheels are sliding, but before enough heat is generated to smear rubber or tar and create skid marks. Third, speed is lost during gaps in the skid marks, and after skid marks end but before the car comes to rest. Fourth, and most important in collisions, is the speed that is lost when the vehicle hits an object. Thus, if the expert witness establishes a minimum speed at or near the reasonable and proper speed, and there is considerable property

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[26] 122 Neb. 679, 241 N.W. 112 (1932).

[27] 171 Neb. 49, 105 N.W.2d 523 (1960).

damage, the jury may reasonably infer that the speed was excessive for the conditions existing at the scene of the accident.[28]

IV. PHYSICAL LAWS RELATING TO SKID MARKS

Expert testimony relating to speeds of vehicles deduced from skid marks involves relatively simple physical and mathematical relationships. A fuller understanding of these relationships should be of value to the judge in permitting such testimony, and to the trial counsel in the use of the expert witness.

The expert witness interpreting skid marks is concerned with: (1) The Laws of Motion; (2) The Law of Conservation of Energy; and (3) Coulomb's Law of Friction or the Coefficient of Friction. A discussion of these laws and examples of their application follow.

A. Laws of Motion

Court testimony in automobile collision cases often involves the mathematical relationships existing between the physical quantities of displacement, time, velocity (directed speed), and acceleration. Of these quantities, displacement and time are considered to be absolute, and velocity and acceleration are related to them by definition.

Velocity is defined as the amount of displacement which occurs during a specified time interval, and is usually expressed in units of miles per hour, or feet per second. When making time and distance calculations it is often necessary to convert from miles per hour to feet per second, or vice versa. The approximate conversion factor 1.5 has been accepted in some courts, with no apparent knowledge of its origin.[29] Actually the ratio 5280/3600 or 1.467 is the correct factor. This factor is based on the number of feet in a mile (5280) and the number of seconds in an hour (3600). This ratio reduces to 88/60, which gives rise to the more precise relationship often used, wherein 88 feet per second is equivalent to 60 miles per hour.

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[28] In Tate v. Borgman, 167 Neb. 299, 303, 92 N.W.2d 697, 700 (1958), the court said that considering the evidence as to the speed necessary to lay down the skid marks, the distance the cab was shoved, the property damage and the force with which the defendant was thrown about the car, "[I]t is obvious that the jury could properly have inferred that defendant's speed was well in excess of the 40 miles per hour she testified to when the brakes took hold and locked the wheels in skid position."

[29] This approximate conversion ratio of 1.5 was used in Biggs v. Gottsch, 173 Neb. 15, 112 N.W.2d 396 (1961). However the testimony of this expert witness was not challenged and the court did not make any decision as to its validity.

Acceleration is defined as the change in velocity which occurs during a specified time interval, and is usually expressed in units of feet per second per second, or in miles per hour per second. When the speed of an automobile changes during some period of its motion, the acceleration must be known in order to make time and distance calculations.

The mathematical relationships which exist between displacement, time, velocity, and acceleration are expressed in the following formulas:

$$(1)\quad s = \frac{(v + v_0)}{2} t, \qquad (2)\quad a = \frac{v - v_0}{t},$$

$$(3)\quad s = \tfrac{1}{2}at^2 + v_0 t, \qquad (4)\quad v^2 = v_0^2 + 2as.$$

In these formulas "s" is the displacement or space passed over, "v" is the final velocity, "v_0" is the initial velocity, "t" is the time interval, and "a" is the constant acceleration. Note that the acceleration must remain constant during the period of motion, otherwise the formulas are not valid. In cases where the acceleration is variable, experimental data are usually required for the determination of certain of the quantities.

Example 1

As an illustration of the use of formula (1) let us assume that we wish to know the distance traveled between the time a driver senses danger, and the time he applies the brakes. This time period is commonly known as the reaction time.[30] The distance traveled is the reaction distance. Let us also assume that this reaction time is three-fourths of a second, a value quite generally used in cases of this sort.[31] There is much evidence to indicate that

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[30] In Tate v. Borgman, 167 Neb. 299, 303, 92 N.W.2d 697, 700 (1958), reaction time was defined as "the time it takes a driver, after he realizes hazard exists, to take his foot from the accelerator and start applying the brake."

[31] Normal reaction time in Nebraska has been recognized to be about three quarters of a second. Tate v. Borgman, 167 Neb. 299, 92 N.W.2d 697 (1958). Recognition of reaction time varies from jurisdiction to jurisdiction. The Wyoming Supreme Court said that it was a matter of common knowledge that reaction time was at least half a second for the average motorist. Kaan v. Kuhn, 64 Wyo. 158, 187 P.2d 138 (1947). In Seeds v. Chicago Transit Authority, 342 Ill. App. 303, 96 N.E.2d 646 (1950), the Illinois Supreme Court while reversing the case said nothing about the appellate court taking notice of the reaction time of at least one second. Some jurisdictions just take note that there must be some passage of time. See Annot., 84 A.L.R.2d 979.

three-fourths of a second is a reasonable reaction time for an average driver who is not anticipating an emergency stop. Let us further assume that the driver is traveling at a speed of seventy miles per hour. Solution:

Converting from miles per hour to feet per second units gives — 70 mi./hr. X 88/60 = 102.7 ft./second. Substituting in

$$s = \frac{v + v_o}{2}(t) \quad \text{gives}$$

$$s = \frac{102.7 + 102.7}{2}(0.75) = 77 \text{ feet.}$$

Example 2

As an illustration of the use of formula (4), let us assume that we wish to know how fast an automobile might be traveling if the driver started from rest and accelerated at a maximum rate of 0.8 g's, (0.8 X 32.2 ft./sec.), continuing this rate of acceleration for a distance of 30 feet. The value of 0.8 g's would correspond to a powerful engine and an exceptionally good traction surface.

Solution:

Substituting in $v^2 = v_o^2 + 2(a)(s)$ gives

$v^2 = 0 + 2(0.8 \text{ X } 32.2)(30) = 1546,$

$v = \sqrt{1546} = 39.3$ ft./sec., converting to mph

gives $v = 39.3(60/88) = 26.8$ mph.

When applying formulas (1) through (4), numerical values must generally be expressed in feet and second units for dimensional consistency. Only two of the four formulas are independent, signifying that only two unknown quantities can be determined from their application, regardless of how many times an application might be made.

The laws of motion have practical application when used alone. For instance, a determination of reaction distance at a given speed may or may not indicate that the speed was excessive with regard to maintaining a proper lookout. However, to arrive at speed calculations it is necessary to consider additional factors.

B. Law of Conservation of Energy & Coulombs Law of Friction

The great increase of stopping distance with increase in speed is rather well known by the general public, due to the efforts of law enforcement officials, licensing agencies and safety organizations. Very often it is assumed that the stopping distance varies as the square of the speed. Data based on this assumption are sometimes used in publicizing the general nature of high speed stopping requirements. The results obtained by the use of the squared relationship are sufficiently accurate for the purpose mentioned, but are not sufficiently accurate for court room testimony.

The physical basis for the squared relationship is found in the Law of Conservation of Energy. This law may be expressed in the form of a mathematical equation which may then be applied to a vehicle being skidded to a stop. The equation states that the kinetic energy of motion is equal to the energy lost in the form of heat generated by tire friction, U_f, in stopping the vehicle. Thus we may write

$$K.E. = U_f \tag{5}$$

Kinetic Energy, K.E., is defined as $\frac{1}{2}\frac{W}{g}v^2$, where "W" is the weight of the moving body in pounds, "v" is the initial velocity of the body in feet per second, and "g" is the standard acceleration of gravity (32.2 ft./sec.^{2}). This is the same "g" that is often mentioned in connection with accelerations in collisions and re-entry forces in space capsules. Work of friction "U_f", is defined as "F x S", where "F" is the force of friction (assumed constant) and "S" is the distance through which the force acts. In case of an automobile, "S" would be the skid mark length. Substitution of the expressions defined as Kinetic Energy and work in formula (5) gives:

$$\frac{1}{2}\frac{W}{g}v^2 = F \times S. \tag{6}$$

A second relationship must now be explained before formula (6) can be applied to solve a practical problem. This relationship is known as Coulomb's Law of Friction. Stated in words, the frictional force "F" divided by the normal force "N" is a constant, *f*, commonly known as the coefficient of friction or drag factor. A mathematical formula for this law is

$$f = \frac{F}{N} \tag{7}$$

Normal force, "N", may usually be taken as the weight of the vehicle, when the slope of the roadway is less than about four percent. The term "normal" is used to describe this force, because it acts normal to the surfaces in contact.

Example 3

As an illustration of the use of formulas (6) and (7) let us assume that we wish to find the speed of a vehicle which has skidded to a stop, having laid down skid marks 150 feet long. Let us further assume that the road surface was asphaltic concrete, dry, free of debris, was in good condition, and was level. For the surface described we will assume a coefficient of friction of 0.6.[32] The several quantities which may be pertinent in the solution are listed below:

W = weight of vehicle (not actually needed in the calculations)
g = 32.2 ft./sec.^{2}, standard acceleration of gravity
F = friction force between tires and roadway
f = 0.6, coefficient of friction (also known as drag factor)
N = normal force (also the weight of the vehicle)
v = initial velocity of the vehicle
s = 150 feet, distance traveled during skid

Solution:

Substituting F, f, and N in formula (7) gives $0.6 = \frac{F}{N}$.

Solving for F gives F = 0.6 N or 0.6W.
By substituting numerical values of v, g, s and F in formula (6) we obtain

$$\frac{1}{2}\,\frac{W}{32.2}\,v^2 = 0.6\ W\ (150).$$

Dividing by W and solving for v gives

$$v = \sqrt{0.6\ (150)\ (2)\ (32.2)} = 76.13 \text{ ft/sec.}$$

Converting to miles per hour gives 76.13 (60/88) = 52 miles per hour.

The foregoing calculations are typical of those used in preparing speed versus skid mark charts. These charts enable one to ascertain the speed of a vehicle directly, without the necessity for making individual calculations.

Inclines of about two percent or more may have a significant effect on stopping distances, and this effect should be accounted for in speed-skid mark calculations. The calculations involved are simple and direct; they are based on the Law of Conservation of Energy discussed previously and expressed mathematically by formulas (5) and (6).

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[32] See discussion of coefficient of friction under Limitations of Calculations, *infra.*

Example 4

As an illustration of how inclines affect stopping distances we will refer to example 3, and change the problem slightly by specifying that the automobile is descending a five per cent grade while attempting to stop.[33] Other conditions are unchanged.

Solution:

In applying formula (6) we must add a term to account for the potential energy possessed by the vehicle at the initial location where the skidding first began. This energy is present by virtue of the vehicle's elevation above the final location where it comes to rest. Equation (6) then becomes:

$$Wh + \frac{1}{2} \frac{W}{g} v^2 = F \times S = f W \times S \qquad (8)$$

where "h" is the vertical distance between the initial and final locations of the vehicle. Vertical distance "h" may be expressed in terms of slope length "S", and per cent grade "h", equals per cent grade multiplied by "S", e.g., h = % grade x S.

By substituting numerical values of "v, g, f, S" and % grade (expressed as a decimal) in formula (8) we obtain

$$W\,(0.05)(150) + \frac{1}{2} \frac{W}{32.2} (v^2) = 0.6\,W\,(150)$$

Dividing out "W" and solving for "v" gives

$$v = 2(32.2)\ (0.6 - 0.05)\ (150) = 72.9 \text{ ft./sec.}$$

Converting to miles per hour gives 72.2 (60/88) = 49.7 mph.

By comparing the results of example 3, (52 mph), and example 5, (49.7 mph), we may conclude that the omission of slope effect in stopping distance calculations might be detrimental to the case of a defendant. Such omission could also be to his advantage.

In the Nebraska cases where an expert has testified on the basis of the facts propounded in a hypothetical question the amount of the slope has been taken into consideration.[34]

Combining the application of the Laws of Motion, the Law of the Conservation of Energy, and the Coefficient of Friction provides the story of speed told by skid marks. Once the minimum speed is established it may be applied to the reaction time to arrive at the minimum reaction distance. Adding the reaction distance

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33 The term skid resistance includes the coefficient of friction (drag factor) plus or minus (±), the slope or grade effect, which is expressed as the vertical rise over the horizontal distance.

34 Biggs v. Gottsch, 173 Neb. 15, 24, 112 N.W.2d 396, 403 (1961); Nisi v. Checker Cab Co., 171 Neb. 49, 55, 105 N.W.2d 523, 527 (1960); Tate v. Borgman, 167 Neb. 299, 303, 92 N.W.2d 697, 700 (1958).

onto the length of the skid marks establishes the point at which the driver saw the impending hazard and took action. The jury then has a basis for determining whether or not the driver was keeping a proper lookout, or whether the driver had his vehicle under sufficient control to cope with the driving conditions. The possibilities for the use of this technique expand when these physical relationships are used to credit or discredit versions of an accident.

C. Limitations of Calculations

Calculated results are only as accurate as the data from which they are calculated. For this reason calculations of speed and stopping distances are limited by the accuracy of the measurements made and the experimental coefficient used. Trial counsel planning on using the expert witness cannot stress too much the need for preserving and obtaining full and complete evidence. The key to the successful use of the expert witness is a prompt, diligent and thorough collection of evidence. An inadequate foundation may be fatal to the use of the expert witness.[35] Important in making use of speed calculations based on skid marks is the measuring of the length of the skid marks. Measurements should be expressed in feet and inches, not in paces. Care must be taken to make certain any overlap of front wheel skid marks with rear wheel skid marks has been accounted for. Preferably, each wheel skid mark should be measured separately, and these measured distances should be averaged. Often the expert witness is not called upon until long after the accident. Therefore, a complete word picture of the accident scene, replete with accurate measurements will insure the successful use of the expert witness.

The value assumed for the coefficent of friction is particularly susceptible to experimental variation. This coefficient may vary from about .05 on smooth ice to about 1.0 on new, sharp concrete paving.[36] The coefficient of friction also varies as the speed of the vehicle changes during a skid. At high speeds, in particular, there is a substantial decrease in the coefficient of friction on most surfaces. Tests have concluded that there is a marked change in the

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[35] Solomon Dehydrating Co. v. Guyton, 294 F.2d 439 (8th Cir. 1961).

[36] The Traffic Institute of Northwestern University, Traffic Accident Investigator's Manual 251 (2d ed. 1954) [hereinafter cited as Traffic Manual]. See appendix A. However, actual experience has shown significant variations. Capt. Witt of the Nebraska Safety Patrol reports that new sharp concrete with brush marks showing has a chewing effect and the resultant drag factor may be actually less than the drag factor on asphalt paving.

coefficient of friction at about thirty miles per hour. For example, at speeds less than thirty miles per hour on dry traveled asphalt or tar paving the range of the coefficient of friction is .60 to .80, at more than thirty miles per hour this range is .55 to .70. When the surface is wet these ranges are .45 to .70 and .40 to .65 respectively.[37]

Other factors which cause measurable differences in the coefficient of friction are variations of tire pressure, temperature of the surface, and the existence of debris on the roadway.

How much of this information is essential in order to offer expert testimony? This question has never been answered by the courts, but a sound rule of thumb would be that all of this information is essential. Each case is unique, and a factor important in one case may not be important in another. However, anything which will alter the coefficient or friction is essential.

Perhaps the most important factor other than the type of surface is whether or not there is debris on the roadway. Debris will always have an effect. If there is an appreciable amount of debris this amount should be noted. Temperature of the road surface will have an effect on asphalt surfaces, especially high temperatures which soften the asphalt and allow the tire tread to grip and give a better coefficient of friction.

Expert testimony is offered as an absolute minimum, and experts frequently assert that their computations favor the driver.[38] If this is the philosophy of the use of expert opinion then the expert opinion should be excluded when factors which have a substantial effect on the coefficient of friction are not taken into consideration in the computations. It is inconsistent on the one hand to assert that the driver is getting the benefit of the doubt, and on the other hand to allow testimony which has no sound basis in fact. The duty to see that expert testimony is based upon fact rather than supposition is ultimately that of the trial counsel who should be prepared to protect the interests of his client.

Other factors have little effect on the stopping distance. Brake pedal pressure affects the speed with which wheels will lock, but once they are locked brake pressure makes no difference. Weight of an ordinary passenger car makes a great difference in stopping distance before the wheels lock, but little difference after they

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37 TRAFFIC MANUAL 251, see appendix A.

38 In discussing the testimony of the expert witness the court in Nisi v. Checker Cab Co., 171 Neb. 49, 55, 105 N.W.2d 523, 528 stated: "He repeatedly stated that the formula used by the Nebraska Safety Patrol actually favors the driver, and is a computation that is very lenient."

lock.[39] It takes more brake pressure to lock the wheels of a heavily loaded car, but the heavier weight increases the force of friction once the brakes are locked. Stopping characteristics of tire tread vary as to the type of road surface. On ordinary surfaces a smooth tire or one with deep tread will stop the car in about the same distance. On loose materials a tire with a tread which will press in provides quicker stopping. On wet surfaces tire treads designed to squeegee off water have good stopping characteristics. On other surfaces, particularly ice, a smooth tread is slightly better because it distributes the weight over a greater area. There is a slight difference in synthetic tires and those made from natural rubber. On mud, snow, and ice, tire chains improve stopping, but on some hard pavements chains may decrease stopping power. Direction of the slide makes a slight but unimportant difference; a tire will slide as easily sideways as it will lengthwise.[40]

The coefficient of friction is an experimental variable. The only way to determine the coefficient of friction or the drag factor is by experimentation. Therefore, when making speed computations using formulas, the coefficient must either be assumed or be determined by an actual experiment. An assumption of the coefficient of friction may be fairly accurate when the assumption is based on past experience gained from experiments. However, an assumption remains nothing more than an "educated guess," and the validity of any subsequent computations is directly dependent upon the accuracy of the assumption.

V. EXPERIMENTAL EVIDENCE

Since the coefficient of friction is an experimental variable, the most reliable speed-skid mark data is therefore obtained by experimentation. The experiment is performed by using a vehicle of comparable weight on a similar surface, and at the approximate speed of the vehicle referred to in the court testimony.

The test should be conducted under very similar conditions to those which existed at the time of the accident. The same type of road surface should be used, and under the same weather conditions. The same tire tread design should be used on wet surfaces, and on softer surfaces such as gravel, dirt, and snow. The exact model and make of car is usually not significant to the result or the reliability of the experiment, but it may be very significant to the skeptical court or juror. Consequently, if the exact make

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[39] This is not necessarily true of trucks, making necessary the consideration of weight when a truck is involved.

[40] TRAFFIC MANUAL, at 243-44.

and model will give the court and jurors more confidence in the expert testimony, counsel or the expert witness should go to the additional effort of finding the exact make and model, putting on similar tire tread design, and duplicating the load of the vehicle at the time of the accident. The ideal situation would be to test the vehicle involved in the accident, but in certain situations this might be very difficult if not impossible. The experiment should be conducted at the scene of the accident. This, besides making it easier to lay a proper foundation for testimony, will do away with the necessity of measuring and calculating the significance of any slope.

The experiment must be under the direction and control of the expert witness. Test skids are made at set speeds. Usually three or four separate skids are made at the same speed. Each skid mark is measured and then an average length is determined. The speed at which the tests are conducted should be reasonably close to the speed alleged by the driver of the car which left the skid marks in the accident. The experiment is usually performed with two men in the car. As the car approaches the test site it is traveling faster than the test speed. The driver releases the accelerator and prepares to jam on the brakes. The second man watches the speedometer and when the test speed is reached he directs the driver to jam on the brakes.

Once the experiment is completed the expert witness has three alternatives. The first alternative is to determine the coefficient of friction by the use of formulas 5, 6, and 7. The coefficient of friction may also be determined from special charts, nomographs, which express the formulas used in the determination.[41] A nomograph of this type would have three proportional lines, representing speed, distance skidded, and the skid resistance (coefficient of friction plus slope influence). The expert witness would draw a straight line connecting the speed and the distance skidded. Then this line extended would indicate the coefficient of friction (drag factor). The second alternative would be to draw additional lines on the nomograph. By drawing a straight line from the coefficient of friction through the distance skidded the minimum speed of the car involved in the accident would be determined. The third alternative would be for the expert witness to testify in court that at certain speeds so many feet of skid marks would result. A range of speeds and resulting skid marks on either side of the speed alleged would be necessary for an adequate comparison.

The use of the nomograph in the first two alternatives, while quite simple, is nevertheless accurate. The nomograph is merely an

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[41] See appendix B.

expression of the formulas used in calculating speed. If the formulas used are correct, and the nomograph is an accurate expression of the formula, then the conclusions derived from the nomograph will be accurate.

The admissibility of results of an experiment, or conclusions drawn from data collected by experimentation, is not an issue in Nebraska. In *McKinney v. Wintersteen*,[42] an expert witness was allowed to testify as to the speed of the defendant's car based on skid marks. This expert based his conclusions on experiments made at the scene of the accident with a car of similar weight and with good brakes. However, the controlling case in this respect is *Crecelius v. Gamble-Skogmo*.[43] This case involved a pedestrian-pickup truck accident in which speed was an issue. At the time of the accident the brakes were greatly out of adjustment. More than two and one-half years after the accident the brakes of a similar model and the same make of pickup truck were adjusted so that the brake pressure was the same as on the vehicle involved in the accident. This vehicle was driven to the scene of the accident and a police officer made various experiments. Testimony adduced was to the length of the skid marks. The court said:[44]

> With regard to the matter of admission of evidence of experiments this court has said: "While experiments are sometimes admitted to illustrate a given subject, we are not aware of any rule that permits onlookers to testify as to the result, without laying the foundation and showing that the result of the experiment can be relied on as a substantive fact. This means that, as a foundation for this testimony, it must be shown that the person who makes the experiment is competent to do so; that the apparatus used was of the kind and in the condition suitable for the experiment, and that the experiment was honestly and fairly made. Without these facts established, 'the result' is without probative force."

The court, recognizing the difficulties in the offer of evidence of experiments, said that unless there was a clear abuse of discretion a judgment would not be reversed.[45]

VI. LAW OF CONSERVATION OF MOMENTUM & THE COEFFICIENT OF RESTITUTION

Closely related to the calculation of speed from skid marks is the calculation of speed based upon the Law of Conservation of Momentum and the Coefficient of Restitution. In practical applica-

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[42] 122 Neb. 679, 241 N.W. 112 (1932).

[43] 144 Neb. 394, 13 N.W.2d 627 (1944).

[44] *Id.* at 400-01, 13 N.W.2d at 631. (Citations omitted).

[45] *Ibid.*

tion these concepts and those used in conjunction with skid marks are closely related, and it will often be necessary to use them in the same accident situation. The use of these various formulas in conjunction with each other will give a more complete picture of events immediately preceding an accident.

The admissibility of expert testimony based on the Law of Conservation of Momentum and the Coefficient of Restitution has not been considered by the Nebraska Supreme Court. However, at least one jurisdiction, Minnesota, has admitted such testimony. The Minnesota Supreme Court in *Storbakken v. Soderberg*,[46] allowed an expert witness to testify as to the velocity of the two vehicles involved at the point of impact and prior thereto. In this case the expert witness, who was a Bachelor of Science in Civil Engineering, a consulting engineer, and an instructor in "Dynamics" at the University of North Dakota, gave testimony based upon the Conservation of Momentum theory. The court said that such testimony was properly permitted, and it was for the jury to give it such weight as it was entitled to under proper instructions.[47] In this case the expert witness did not assume or calculate the speed of either car. He, however, established a ratio, and this ratio of the speeds was used to discredit the defendant's version of the accident. The admission of this testimony was held to be within the discretion of the trial court.

In view of the acceptance in Nebraska courts of testimony of expert witnesses regarding skid marks and speed, it is not unreasonable to assume that the Nebraska Supreme Court would probably permit testimony based on the Law of Conservation of Momentum and on the Coefficient of Restitution. Certainly the test for expert testimony, that the subject be beyond the comprehension of the average juror, is met.[48]

A. Speed Calculations Based on the Law of Conservation Of Momentum

When two bodies collide, their velocities immediately before and after collision are related in a definite way in accordance with the Law of Conservation of Momentum. This physical relationship forms a basis for calculations which make possible the determination of the speed of a vehicle involved in a collision, if certain other quantities are known.

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[46] 246 Minn. 434, 75 N.W.2d 496 (1956).

[47] *Id.* at 441, 75 N.W.2d at 501.

[48] Testimony based upon the Law of Conservation of Momentum has been allowed in lower courts in Nebraska.

The Law of Conservation of Momentum states that the sum of the momentae of two bodies before impact is equal to the sum of their momentae after impact. Momentum is defined as the product of the mass of a body, (W/g), and its linear velocity. The above two statements may be expressed mathematically by the equation

$$\frac{W_1v_1}{g} + \frac{W_2v_2}{g} = \frac{W_1v_1'}{g} + \frac{W_2v_2'}{g}$$

where "W_1" and "W_2" are the weights of the bodies, "v_1" and "v_2" are the velocities of the two bodies immediately before impact, and "v_1'" and "v_2'" are the velocities of the two bodies immediately after impact. Standard acceleration of gravity "g" may be cancelled from both sides of the equation leaving: $W_1v_1 + W_2v_2 = W_1v_1' + W_2v_2'$. (9)

Example 5

As an illustration of the use of formula (9) let us assume that we wish to find the velocity of a vehicle which has struck a second vehicle head-on. Let us further assume that both vehicles remain in the same location after the collision, so that the final velocities "v_1'" and "v_2'" are zero. Other data are as follows:

W_1=3000 lb., weight of vehicle #1

W_2=5000 lb., weight of vehicle #2

v_2 =45 mph, speed of vehicle 2 immediately before impact.

Solution:

Substituting numerical values in formula (9) gives

$$3000\ (v_1) + 5000\ (45) = 0$$

from which

$$v_1 = \frac{-5000\ (45)}{3000} = -75 \text{ mph}$$

The minus sign in the answer indicates that the velocities of the vehicles before collision were in opposite directions.

B. NEWTON'S LAW OF RECOVERY—COEFFICIENT OF RESTITUTION

An experimental law known as the Law of Recovery may be used in some instances to supplement the Law of Conservation of Momentum and the Law of Conservation of Energy. Like Coulomb's Law of Friction, (coefficient of friction), this law depends upon an experimental constant for its formulation and application to practical problems. The law states that for two bodies which collide, the relative velocities of separation divided by the relative velocities of approach is a constant, commonly known as the coefficient of restitution, "e". A mathematical formula for this law is

$$e = \frac{v_2' - v_1'}{v_1 - v_2} \qquad (10)$$

where "v_1" and "v_2" are the speeds of two bodies immediately before impact, and "v_1'" and "v_2'" are their speeds immediately after separation. The Law of Recovery for vehicles involved in a collision, might be stated thus: The separating speed after impact divided by the closing speed before impact is a constant known as the coefficient of restitution.

The coefficient of restitution has a physical significance as a measure of the elastic (rebound) property and the plastic (permanent deformation) property of bodies in collision. Thus, a high coefficient of restitution would be indicated by a golf club striking a golf ball, whereas a low coefficient of restitution would be indicated by a ball of mud striking a wall. In automobile collisions at low speeds, *e.g.*, under five mph, where bumpers may strike but suffer little permanent deformation, the coefficient of restitution is quite high, perhaps as high as 0.9. But, at high speeds where there is extensive body damage, it is quite low, approaching zero for direct broadside and head-on collisions. A value of the coefficient of restitution of 1 indicates perfect elasticity, and a value of zero indicates perfect plasticity; these are the limiting values possible for the coefficient of restitution.

Example 6

As an illustration of the use of the Law of Recovery as set forth in equation (10), let us assume that we wish to find the speed of a vehicle which has struck a second vehicle from the rear, causing a relatively small amount of bumper damage, but no body or frame damage. Let us further assume that the second vehicle was traveling at a speed of twenty mph, and that after the impact its speed was immediately increased to thirty mph. Let us also assume that the first vehicle weighed 3000 pounds, that the second vehicle weighed 4000 pounds, and that no brake application was indicated.

Solution:

For this situation we will first assume a relatively high value of the coefficient of restitution of 0.9. Substituting numerical values of speeds before and after collision in formula (10) we obtain

$$0.9 = \frac{30 - v_1'}{v_1 - 20}.$$

Clearing the equation of fractions and simplifying we obtain

$$0.9(v_1 - 20) = 30 - v_1'$$

and $$v_1' = 48 - 0.9v_1. \qquad (11)$$

Since equation (11) contains two unknown quantities, it cannot be solved for a numerical value. However, we may obtain another expression containing the same two unknown quantities from formula (9), which is based on the Law of Conservation of Momentum. By substituting numerical values of weights of vehicles and speeds before and after collision in formula (9), we obtain

$$3000(v_1) + 4000(20) = 3000(v_1') + 4000(30).$$

Dividing both sides of the equation by 3000 and simplifying gives

$$v_1 = v_1' + 13.33. \qquad (12)$$

Substituting v_1' from (11) in (12) gives

$$v_1 = 48 - 0.9v_1 + 13.33.$$

Solving gives $v_1 = 32.3$ mph which is the speed of the first vehicle immediately before impact.

Similar calculations for coefficients of restitution yield results according to the following table:[49]

Coefficient of Restitution	Vehicle speed before impact, mph
.0	43.3
0.2	39.4
0.5	35.5
0.8	33.0
0.9	32.3
1.0	31.9

With these results available, an expert witness would be justified in stating that the speed of the first vehicle immediately before impact under the conditions assumed would be between thirty two and thirty five mph.

In a more complex problem it may be necessary to apply several of the physical laws which have been illustrated by the above six examples, in order to make a determination of the speed of a vehicle in question. When problems of this sort are encountered their analysis and solution must be based on good judgment developed by experience and aided by mathematical relationships which have been formulated from the physical laws. To set up and solve such a complex hypothetical problem would be beyond

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[49] This table is an example where a range of possible speeds could be presented to the jury, but the exact speed could not be determined because of the difficulty of determining the exact coefficient of restitution. Such a range would give the jury the extremes and a basis for its conclusion.

the scope and intent of this paper, since a larger mathematical background might be required for complete understanding than has been assumed. However, a person who had completed courses in Statics and Dynamics in the field of Engineering Mechanics, as taught in colleges throughout the United States, would have the necessary theoretical background. Such a person should have some practice in applying the theoretical knowledge to practical problems, and some experience in the behavior of automobiles during periods of collision, in order to make meaningful calculations and to qualify as an expert witness, if necessary.

VII. CURRENT USE OF EXPERT TESTIMONY

Speed-skid mark calculators of different types have been devised for use in finding the speed of a vehicle, if the skid mark distance, grade of the incline, and average coefficient of friction are known. These calculators have the form of alignment charts (nomographs)[50] and slide rules. To use these calculators it is necessary to first determine the drag factor (coefficient of friction $\pm$ the slope effect). By matching the distance skidded with the drag factor, the various calculators will yield the minimum speed at which the vehicle was traveling.

In Nebraska there are three primary groups or classes of expert witnesses in the interpretation of skid marks. These groups are the Nebraska Safety Patrol, local police departments, and college professors. Everyone that falls into these three classes does not necessarily qualify as an expert witness. Nebraska Safety Patrolmen and local police must be experienced accident investigators in addition to being familiar with the principles and application of the formulas used to calculate speed. These qualifications are usually established by the witness's personal history as an accident investigator and his graduation from the Traffic Institute at Northwestern University.[51] College professors who qualify as expert witnesses are instructors in physics or dynamics who are very familiar with the applicable formulas and theories and who have made studies of automobile accidents and the actual applications of the formulas to be used in their determinations.[52] Any expert witness must testify that he has personally verified the accuracy of the method which he will use in his testimony.

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[50] See appendix B.

[51] Nisi v. Checker Cab Co., 171 Neb. 49, 105 N.W.2d 523 (1960); Tate v. Borgman, 167 Neb. 299, 92 N.W.2d 697 (1958).

[52] Lofton v. Agee, 303 F.2d 287 (8th Cir. 1962); Solomon Dehydrating Co., 294 F.2d 439 (8th Cir. 1962).

The actual court room testimony is a statement of the factors considered and then the conclusion. The formulas are not usually explained or applied before the court. The expert witness makes his calculations prior to the trial, and at the trial he simply states that it is his opinion that the car was traveling at a minimum speed of so many miles per hour.

State Safety Patrolmen and local police officers who testify as expert witnesses usually base their conclusions upon the use of the various calculators. The coefficient of friction or drag factor is either estimated or determined by experiments, with either method being accepted by the courts.[53] Convenience would appear to be an important factor in deciding whether skid tests will be made. As a matter of practical consideration it is often difficult to block a segment of heavily traveled street or highway to conduct an experiment. Therefore, if the expert is familiar with the type of road surface, and has made previous experiments on similar surfaces, he will estimate the coefficient of friction.

College professors who qualify as expert witnesses are more prone to determine the coefficient of friction or drag factor by experimentation. Once the coefficient is established the college professor will apply this coefficient to a formula computation rather than use a mechanical calculator. In addition, when the professor makes his determination he is in a position to give further testimony with regard to the accident because of the application of other theories and formulas as discussed under the Law of Conservation of Momentum, *supra*.

Are speed determinations derived from the application of physical formulas more accurate than those derived from the use of calculators? Generally, the accuracy would be about the same. The principal source of error in any speed calculation lies in the accuracy of the determination of the drag factor. But if there is an error in determining the drag factor it will have the same effect whether a calculator or formulas are used to determine the speed. The theoretical basis for the calculators is the Law of Conservation of Energy, previously mentioned. They are a compilation, in graphical form, of a number of solutions of the general equation of conservation of energy, with different coefficients of friction assumed. The charts are theoretical in character, and are subject to error only in their application. When properly applied, they provide a convenient means for determining vehicle speeds.

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[53] Query? In a criminal action where the quantum of proof is generally greater, should an estimate as to the coefficient of friction (drag factor), a vital element, suffice?

It should be remembered that calculators were developed with reference to cars, and their use may not transfer to other vehicles. Speed-skid mark data for heavy trucks, particularly for semi-trailers, are not generally available. It is known, however, that the coefficient of friction is somewhat lower, on most surfaces, for heavy trucks than for passenger cars. This variation is probably due to the higher truck tire pressures and the accompanying higher unit loading on the road surface. In the case of trucks, it becomes even more important to make an actual test to determine the correct value of the coefficient of friction.[54]

Another possible source of error in using a speed-skid mark calculator lies in improper application to a vehicle which does not come to a full stop. The charts are prepared with a full stop assumed, and therefore should not be used in any other condition, except to indicate that the vehicle must have been traveling above a certain minimum speed. Even then, any statement made might be misleading, as will be illustrated by the following example. Let us assume that an auto were to skid seventy feet on a surface having a coefficient of friction of 0.6, and then strike a parked vehicle, doing appreciable damage. This damage we will estimate, for the purpose of illustration, as being due to a collision speed of twenty miles per hour. Now we shall apply the skid mark chart to the moving auto, obtaining a speed of at least 35 miles per hour. Misleading information might be conveyed here, because a jury would very likely add the estimated impact damage speed of twenty miles per hour to the skid mark chart indicated speed of 35 miles per hour, and conclude that the initial speed of the auto was fifty five miles per hour. A correct solution of this type of problem entails a direct application of the general equation of Conservation of Energy, without resorting to speed-skid mark charts. By applying the Law of Conservation of Energy the correct speed would be forty miles per hour, a difference of fifteen miles per hour.

Generally how accurate is the testimony given by expert witnesses? Giving the driver the benefit of the doubt, there is a five to eight percent margin of error. When calculators are used the margin of error is about eight percent.[55] When skid tests are made and formulas are used this margin of error is reduced to about five percent. It should be remembered that these represent somewhat

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[54] Total weight and weight distribution of the truck involved in the accident must be duplicated in any test to determine the coefficient of friction.

[55] Baker, *Open Forum-Scientific Reconstruction of an Automobile Accident,* 25 INS. COUNSEL J. 438, 439 (1958).

maximum margins. Within these limits there are off setting effects which reduce the amount of error but can not be accurately determined, *e.g.*, the fact that it takes longer to lock the brakes of a heavy car but, once the brakes are locked, there is a greater frictional force.

It is submitted that even with this margin of error that expert testimony should be allowed. First, these margins give the driver the benefit of the doubt and the actual speed is probably less than the limits of the margin of error. Second, even when allowing the full margin the speed may still be excessive. Third, expert testimony is often necessary where there are no independent witnesses to testify to the speed of the vehicles. And fourth, expert testimony is more certain than testimony of lay witnesses, who may not have had the vehicle in view long enough to determine its speed, or were not thinking of speed at the time, or were influenced by sound which is often falsely related to speed, or were distracted from observing the speed of the vehicle by other facets of the accident situation, a situation which often starts and reaches a conclusion in a matter of seconds.

VIII. CONCLUSION

It has been the intent of this paper to show in their legal context the simple applications of the fundamental physical laws which apply to the motion of automobiles during periods of acceleration, periods of braking, and to the motion of vehicles resulting from collision. The examples selected are not intended to instruct the reader in a general procedure for solving problems surrounding automobile collisions, for such use of the physical laws without a background of experience could do more harm than good.

It is hoped that by reference to this paper a more lucid picture of the physical and mathematical relationships which apply to automobile collisions may be obtained. It is believed that with more complete knowledge the appropriateness of expert witness testimony may be more confidently evaluated, and that through proper admission as evidence, the cause of justice might be served.[56]

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[56] Appendices A and B, taken from the TRAFFIC ACCIDENT INVESTIGATOR'S MANUAL FOR POLICE (2d ed. 1954), are reprinted by permission of the Traffic Institute, Northwestern University.

APPENDIX A

Possible Ranges of Pavement Drag Factors for Rubber Tires

DESCRIPTION OF ROAD SURFACE	DRY				WET			
	Less Than 30 m.p.h.		More Than 30 m.p.h.		Less Than 30 m.p.h.		More Than 30 m.p.h.	
	From	To	From	To	From	To	From	To
Concrete								
New, Sharp	.80	1.00	.70	.85	.50	.80	.40	.75
Travelled	.60	.80	.60	.75	.45	.70	.45	.65
Traffic Polished	.55	.75	.50	.65	.45	.65	.45	.60
Asphalt or Tar								
New, Sharp	.80	1.00	.65	.70	.50	.80	.45	.75
Travelled	.60	.80	.55	.70	.45	.70	.40	.65
Traffic Polished	.55	.75	.45	.65	.45	.65	.40	.60
Excess Tar	.50	.60	.35	.60	.30	.60	.25	.55
Brick								
New, Sharp	.75	.95	.60	.85	.50	.75	.45	.70
Traffic Polished	.60	.80	.55	.75	.40	.70	.40	.60
Stone Block								
New, Sharp	.75	1.00	.70	.90	.65	.90	.60	.85
Traffic Polished	.50	.70	.45	.65	.30	.50	.25	.50
Gravel								
Packed, Oiled	.55	.85	.50	.80	.40	.80	.40	.60
Loose	.40	.70	.40	.70	.45	.75	.45	.75
Cinders								
Packed	.50	.70	.50	.70	.65	.75	.65	.75
Rock								
Crushed	.55	.75	.55	.75	.55	.75	.55	.75
Ice								
Smooth	.10	.25	.07	.20	.05	.10	.05	.10
Snow								
Packed	.30	.55	.35	.55	.30	.60	.30	.60
Loose	.10	.25	.10	.20	.30	.60	.30	.60
Metal Grid								
Open	.70	.90	.55	.75	.25	.45	.20	.35

Exhibit 52-4. The drag factor or coefficient of friction of a pavement of a given description may vary considerably because quite a variety of road surfaces may be described in the same way and because of some variations due to weight of vehicle, air pressure in tire, tread design, air temperature, speed and some other factors. These figures represent experiments made by many different people in all parts of the U. S. They are for straight skids on clean surfaces. Speeds referred to are in the beginning of the skid.

APPENDIX B

SPEED ESTIMATES

SKIDMARK SPEED CALCULATOR

$$S = 5.5\sqrt{D(F \pm h)}$$